LIVING WITH A LARGE REDUCTION IN PERMITED LOADING BY USING A HYDROGRAPH-CONTROLLED RELEASE SCHEME

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Abstract. The Total Maximum Daily Load (TMDL) for ammonia and biochemical oxygen demand for the Pee Dee, Waccamaw, and Atlantic Intracoastal Waterway system near Myrtle Beach, South Carolina, mandated a 60-percent reduction in point-source loading. For waters with a naturally low background dissolved-oxygen concentrations, South Carolina anti-degradation rules in the water-quality regulations allows a permitted discharger a reduction of dissolved oxygen of 0.1 milligrams per liter (mg/L). This is known as the "0.1 rule." Permitted dischargers within this region of the State operate under the "0.1 rule" and cannot cause a cumulative impact greater than 0.1 mg/L on dissolved-oxygen concentrations. For municipal water-reclamation facilities to serve the rapidly growing resort and retirement community near Myrtle Beach, a variable loading scheme was developed to allow dischargers to utilize increased assimilative capacity during higher streamflow conditions while still meeting the requirements of a recently established TMDL.

As part of the TMDL development, an extensive real-time data-collection network was established in the lower Waccamaw and Pee Dee River watershed where continuous measurements of streamflow, water level, dissolved oxygen, temperature, and specific conductance are collected. In addition, the dynamic BRANCH/BLTM models were calibrated and validated to simulate the water quality and tidal dynamics of the system. The assimilative capacities for various streamflows were also analyzed.

The variable-loading scheme established total loadings for three streamflow levels. Model simulations show the results from the additional loading to be less than a 0.1mg/L reduction in dissolved oxygen. As part of the loading scheme, the real-time network was redesigned to monitor streamflow entering the study area and water-quality conditions in the location of dissolved-oxygen "sags." The study reveals how one group of permit holders used a variable-loading scheme to implement restrictive permit limits without experiencing prohibitive capital expenditures or initiating a lengthy appeals process.

Keywords: Total Maximum Daily Load, hydrograph-controlled release, water-quality model, real-time data monitoring, variable loading, Pee Dee River, Waccamaw River, Atlantic Intracoastal Waterway

1. Introduction

The Grand Strand is a rapidly growing resort area on the northeastern coast of South Carolina (Figure 1). The municipalities of Myrtle Beach and North Myrtle Beach have experienced tremendous growth in the 1990's and have become the second largest summer tourist destination on the East Coast. As a result, demands on the water resources continue to increase.

The Total Maximum Daily Load (TMDL) for ammonia and biochemical oxygen demand determined by the South Carolina Department of Health and Environmental Control for the Pee Dee, Waccamaw, and Atlantic Intracoastal Waterway system mandated a 60-percent reduction in point-source loading (South Carolina

Department of Health and Environmental Control, 1999). Antidegradation rules in the South Carolina Department of Health and Environmental Control regulations allow a maximum deficit of 0.1 milligrams per liter (mg/L) where waters do not meet the numeric standard for dissolved oxygen because of natural conditions. This is known as the "0.1 rule" (South Carolina Department of Health and Environmental Control, 1993). Although the municipal water-reclamation facilities utilize land application of effluent to meet the restrictive permit limits based on the "0.1 rule," there are periods during wet weather when land application to saturated soil is not an option.

The Grand Strand Water and Sewer Authority is responsible for providing water and wastewater services to the majority of Horry County, and has been deeply involved in water-resource planning issues along coastal South Carolina. The Au-

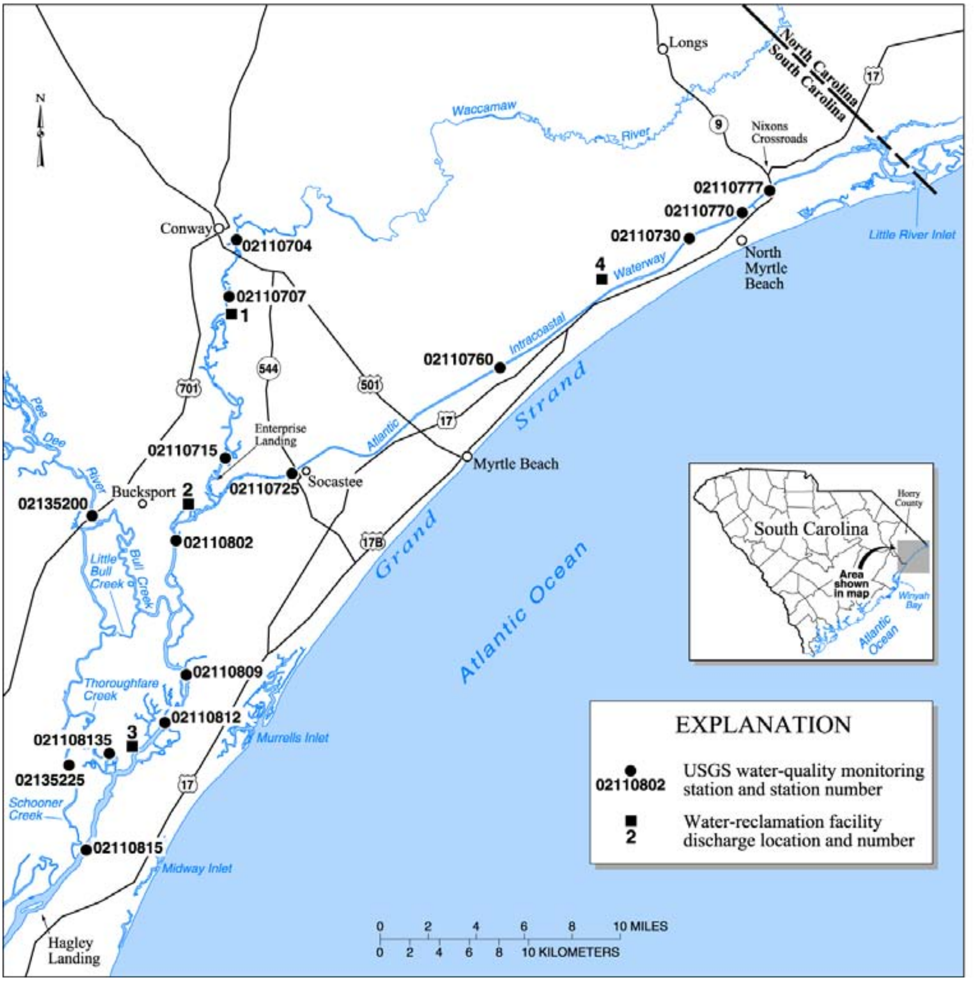

Figure 1. Location of real-time water-quality monitoring stations and water-reclamation facility discharge points.

thority, working with Jordan, Jones & Goulding, Inc., and the U.S. Geological Survey (USGS), developed a wastewater-release scheme that would maximize the increased assimilative capacity of the rivers during wet weather conditions when land application is not viable.

2. Description of Study Area

The Pee Dee and Waccamaw River Basins, approximately 13,000 and 1,300 square miles, respectively, supply freshwater inflow to the Grand Strand in the coastal zone, an increasingly developing strip of communities along the South Carolina coast from Little River Inlet to the north and Winyah Bay to the south. Inland and south of the U.S. Highway 701 Bridge, the Pee Dee River branches successively into Bull, Thoroughfare, and Schooner Creeks (Figure 1). These three creeks eventually flow into the Waccamaw River, with their net flows discharging 25 miles southward into Winyah Bay.

The Waccamaw River originates in North Carolina and enters the Atlantic Intracoastal Waterway about 10 miles north of the mouth of Bull Creek. Prior to the 1930's, the Waccamaw River flowed to the south toward Winyah Bay. In the 1930's, the U.S. Army Corps of Engineers constructed a canal to form the waterway from Enterprise Landing to the Little River Inlet, which altered the flow of the Waccamaw River north toward Little River Inlet along the Atlantic Intracoastal Waterway.

The majority of the freshwater flow to the segment of the Waccamaw River south of its junction with the waterway is from the Pee Dee River Basin and is carried by Bull Creek. The annual average streamflow from the Pee Dee Basin is about 14,100 cubic feet per second (ft^3/s), which is the combined streamflow of the three major rivers (Pee Dee, Little Pee Dee, and Lynches Rivers) (Carswell, *et al.*, 1988). The Pee Dee River (downstream from the confluence with the Little Pee Dee River), Bull Creek, and Thoroughfare Creek are tidally affected during low and medium streamflows. The annual average streamflow of the Waccamaw River at Longs is 1,220 ft^3/s. The net streamflow of the Atlantic Intracoastal Waterway at the confluence with the Waccamaw River is north towards Little River Inlet from the Waccamaw River (Carswell, *et al.*, 1988).

Saltwater enters the Atlantic Intracoastal Waterway through Winyah Bay to the south and Little River Inlet to the north. The Atlantic Intracoastal Waterway is affected by semidiurnal tides throughout the entire reach with a mean tide range of 4.0 feet (ft) at Nixons Crossroads and 3.5 ft at Hagley Landing (National Oceanic and Atmospheric Administration, 1995). The Pee Dee and Waccamaw Rivers are tidally affected during low and medium streamflows downstream of U.S. Highway 701 and U.S. Highway 501 bridges, respectively.

Point-source loads occur at four locations in the study area where (Figure 1) Grand Strand Water and Sewer Authority operate facilities in each of the locations. Prior to the recent TMDL, the total permitted loading to the system was 28,230 pounds per day of ultimate oxygen demand. The critical period analysis performed by South Carolina Department of Health and Environmental Control for the TMDL indicates that during low-flow regimes, a substantial reduction in total loading of ammonia and biochemical oxygen demand is required to maintain water-quality standards. Based on the flow period and critical condition boundary loadings for June 1, 1994, through July 15, 1994, a total assimilative capacity of 10,668 pounds per day of ultimate oxygen demand was determined. A summary of previous permit limits and the TMDL limits are shown in Table 1.

3. Approach

Models were used to simulate the unsteady streamflow, and the fate and transport of nutrients, biochemical oxygen demand, and dissolved oxygen in the Waccamaw and Pee Dee Rivers and in the Atlantic Intracoastal Waterway. The one-dimensional, dynamic flow BRANCH model (Schaffranek and others, 1981) was used to compute the two-way, tidal flow sand hydraulic properties of the riverine/estuarine system. Because the BRANCH model does not simulate the transport of constituents, it was necessary to use the one-dimensional dynamic Branched Lagrangian Transport Model (BLTM)(Jobson, 1997; Jobson and Schoelhamer, 1993) to simulate the mass transport and transformations of nutrients, biochemical oxygen demand, and dissolved oxygen.

As part of the TMDL development, the USGS, in cooperation with the Waccamaw Regional Planning and Development Council, applied the BRANCH and BLTM models to the Waccamaw River, Pee Dee River, Bull Creek, and Atlantic Intracoastal Waterway (South Carolina Department of Health and Environmental Control, 1999). As part of the model application, an extensive real-time data-collection network was established in the lower Waccamaw and Pee Dee River watersheds where continuous measurements of streamflow, water level, dissolved oxygen, temperature, and specific conductance are recorded (Figure 1). The two models were calibrated and validated to simulate the water quality and tidal dynamics of the

Table 1. Previous permit limits and TMDL limits for four discharge locations in the Grand Strand

[UOD, ultimate oxygen demand; TMDL, Total Maximum Daily Load]

Location	*Previous Permit Limits in UOD (pounds per day)*	*TMDL limits in UOD (pounds per day)*
Conway	1,873	303
Bucksport	228	84
Hagley	24,220	8,643
North Myrtle Beach	1,909	1,638
Total	28,230	10,668

system. Results from these models indicate that the assimilative capacity is dependent upon the selected flow conditions (Drewes and Conrads, 1995).

The flow period selected to analyze for critical conditions used for the TMDL determination was based on a review of several years of flow data collected by the USGS during model development; however, the selected critical flow period is considered analogous to the lowest 7-day average, 10-year recurrence streamflow typically used for assimilative capacity analyses. It is typical to further analyze the assimilative capacity of surface waters using higher flow regimes on either a seasonal or hydrograph-controlled release basis. Under a hydrograph-controlled release permit, dischargers are able to utilize the increased assimilative capacity during periods of higher streamflow. This seasonal analysis is consistent with the TMDL policy of the U.S. Environmental Protection Agency and is commonly utilized by South Carolina Department of Health and Environmental Control.

During the draft National Pollution Discharge Elimination System permitting process, South Carolina Department of Health and Environmental Control agreed to allow variable ultimate oxygen demand loadings based on actual streamflows, but specified that the variable loadings must be calculated using the dynamic model developed for the Waccamaw River and Atlantic Intracoastal Waterway system in order to be consistent with the previous analysis. To determine the assimilative capacity of various flow regimes, the BRANCH and BLTM models were used to simulate the streamflow and water quality for various flow conditions between 1990 and 1994. The hydraulic data for the BLTM were simulated with the BRANCH model by using measured water levels at the model boundaries. For consistency between model simulations for various flow periods, the only inputs to the model that were modified for each simulation were the historical period selected for the water-level time series used in the BRANCH model to simulate the flow and hydraulic characteristics of the system. All other inputs to the model, including water-quality conditions and meteorological conditions, remained unchanged.

Due, in part, to drainage from extensive wetlands and the relatively low flushing rate of this system, dissolved-oxygen concentrations tend to be naturally low, often lower than the 4.0 mg/L minimum required for these coastal waters in South Carolina. Additional point sources of ultimate oxygen demand loads may be permitted if they do not cause a cumulative impact to the dissolved-oxygen concentration of greater than 0.1 mg/L. The "0.1 rule" was applied consistent with the critical period analysis to determine the point-source loadings at varying flow periods. "Background" conditions were estimated by removing the point-source loadings (both pipe flow and effluent concentration) from the model and determining the resultant dissolved-oxygen profile. The next step was to include the point-source loadings in the model and to determine the associated dissolved-oxygen profile. The result of the proposed discharges is the difference between the background or no-load scenario and the load scenario.

The dynamic model BRANCH/BLTM developed for the Waccamaw and Atlantic Intracoastal Waterway system was used to analyze the tiered hydrograph-controlled release scheme. Programs were developed by USGS staff to analyze the flow data files, determine which streamflow tier would apply, input the load file, and then run the model. Model simulations were run for 45-day periods. The first 15 days were used as a "warm up" period and the assimilative capacity analysis was performed during the last 30 days. The load and no-load scenarios were then compared to verify that the "0.1 rule" was maintained. The process of determining the tier loading rates was an iterative process of selecting streamflow thresholds, determining loading amounts, and evaluating the water-reclamation facility operational feasibility of the hydrograph-controlled release.

Jordan, Jones, and Goulding performed an analysis of the USGS flow period records and associated statistical occurrences. The selection of higher flow levels for model analysis was based on meeting the following goals:

- Maintain all water-quality standards;
- Simplify South Carolina Department of Health and Environmental Control's review of permit compliance;
- Minimize complicated discharge decisions for water-reclamation facility operating staff; and
- Remain consistent with U.S. Environmental Protection Agency's TMDL policy (South Carolina Department of Health and Environmental Control, 1991).

4. Results

A three-tiered release schedule was determined to best meet all of the intended goals of the proposed hydrograph-controlled release scheme. These tiers are defined in Table 2. Specified minimum flow regimes must only occur in one of the streams to trigger an individual tier loading. For example, if flows in the Waccamaw River are less than 1,000 ft^3/s whereas flows in the Pee Dee River are 8,000 ft^3/s, then tier 1 loadings would apply.

Based on an analysis of the flow records from USGS gaging stations in the Waccamaw and Pee Dee River Basins, tier 1 flows (and critical period loadings) would occur approximately 51 percent of the time. Tier 2 flows (and loadings) would occur approximately 27 percent of the time, and tier 3 flows (and loadings) about 22 percent of the time.

5. Model Analysis

A tiered hydrograph-controlled release concept was evaluated using the Waccamaw and Atlantic Intracoastal Waterway model used for the TMDL development. This concept allows for additional loadings during flow regimes higher than the critical period while still protecting water-quality standards. Three separate flow periods

Table 2. Summary of tier streamflows and loadings

Tiers and Streamflow Levels	*Percent of Time Flow Occurs*	*Discharge Location*	*Loading (pounds per day UOD)*
Tier 1	51	Conway	303
Pee Dee River < 6,000 ft^3/s		Bucksport	84
or		Hagley	8,643
Wacamaw River < 1,000 ft^3/s		North Myrtle Beach	1,638
		Total	**10,668**
Tier 2	27	Conway	574
6,000 ft^3/s < Pee Dee River		Bucksport	121
< 10,000 ft^3/s		Hagley	12,955
or		North Myrtle Beach	2,446
1,000 ft^3/s < Waccamaw River		**Total**	**16,096**
< 2,500 ft^3/s			
Tier 3	22	Conway	956
Pee Dee River > 10,000 ft^3/s		Bucksport	201
or		Hagley	21,592
Waccamaw River > 2,500 ft^3/s		North Myrtle Beach	4,077
		Total	**26,827**

were selected to validate the tiered-concept approach. Each flow period exhibited unique flow characteristics and is considered appropriate for this analysis. A summary of the flow periods selected and the associated results is provided below.

December 1990 Flow Period

Flows in the Waccamaw River generally averaged less than 1,000 ft^3/s during December 1990 with periodic values greater then 1,000 ft^3/s (tiers 1 and 2). Flows in the Pee Dee River generally averaged between 10,000 and 15,000 ft^3/s (tier 3). The amount of permissible loading was controlled by the lower flows in the Waccamaw River, and varied between tiers 1 and 2 during this simulation. Water-quality standards for dissolved oxygen were maintained during this flow scenario.

February 1992 Flow Period

Flows in the Waccamaw River averaged between 2,000 and 5,000 ft^3/s (tiers 2 and 3) during February 1992 (Figure 2). Flows in the Pee Dee River generally ranged between 5,000 and 17,000 ft^3/s (tiers 1, 2, and 3). The amount of permissible loading was controlled by the lower threshold flows of the Pee Dee River, and varied between tiers 1 and 3 during this simulation. The differences in dissolved-oxygen concentration between the load and no-load scenarios ranged between 0.03

and 0.09 mg/L. Water-quality standards for dissolved oxygen were maintained during this flow scenario.

November 1992 Flow Period

Flows in the Waccamaw River varied between 100 and 4,500 ft^3/s during November 1992 (tiers 1, 2, and 3). Flows in the Pee Dee River generally ranged between 12,000 and 32,000 ft^3/s (tier 3). Permissible loading was controlled by the lower tier streamflows of the Waccamaw River which varied between tiers 1, 2, and 3 during this simulation. Of the three flow periods, the November 1992 period was the most dynamic. Early in the simulation, the system was controlled by tier 1 streamflow and loading conditions. The difference in dissolved-oxygen concentrations between the load and no-load scenarios was 0.09 mg/L. As streamflows increased in the Waccamaw River, the loading increased to tiers 2 and 3. The resulting differences in dissolved-oxygen concentration decreased to 0.02 mg/L, well below the allowable dissolved-oxygen reduction of 0.1 mg/L (Figure 3).

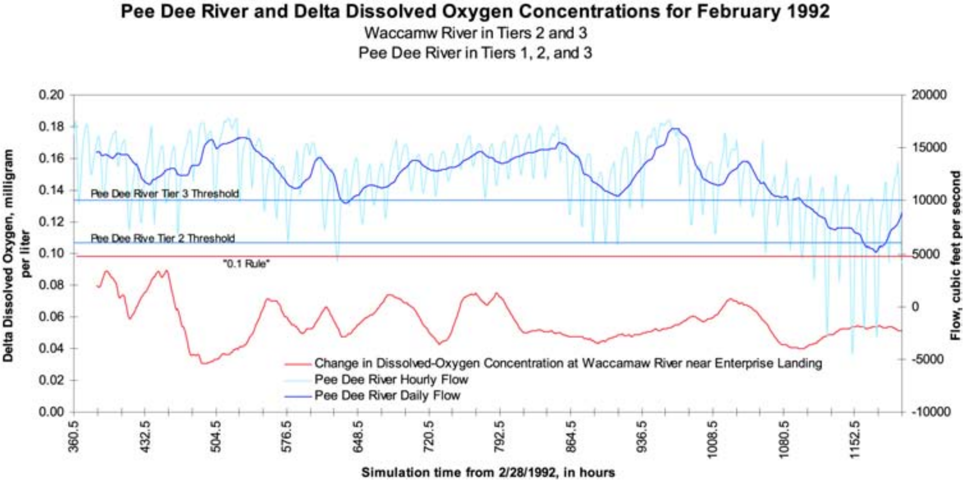

Figure 2. Simulated streamflow for the Pee Dee River and dissolved-oxygen differences for the Waccamaw River at Enterprise Landing for February 1992.

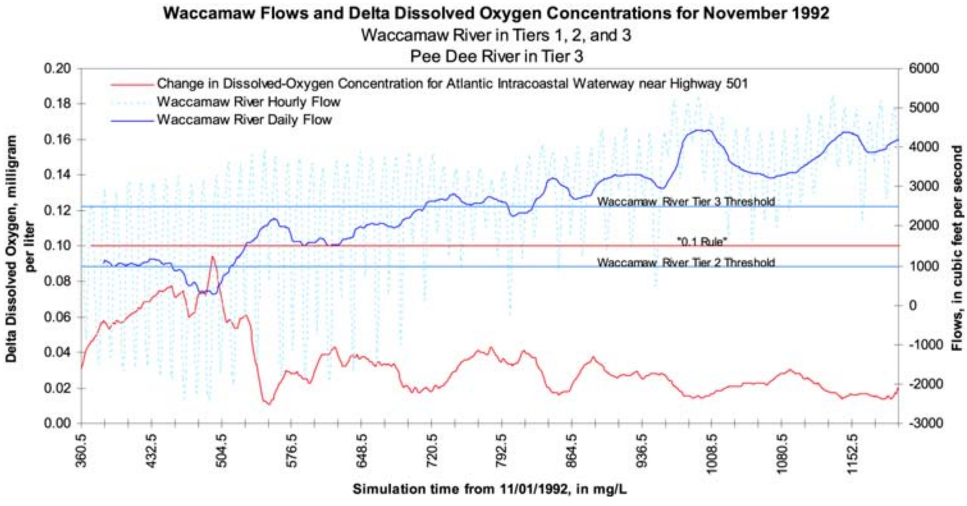

Figure 3. Simulated streamflow for the Waccamaw River and dissolved-oxygen differences for the AIW near Highway 501 November 1992.

6. Summary and Implementation

The tiered hydrograph-controlled release concept for the Pee Dee, Waccamaw, and Atlantic Intracoastal Waterway system was based on the variable flows typically experienced, which is consistent with U.S. Environmental Protection Agency's TMDL policy. Antidegradation rules in the South Carolina Department of Health and Environmental Control regulations allow a maximum deficit of 0.1 mg/L where waters do not meet the numeric standard for dissolved oxygen because of natural conditions. The "0.1 rule" was applied to the model simulations using the dynamic model developed by the USGS and approved by South Carolina Department of Health and Environmental Control for TMDL analyses. By selecting variable discharge loadings that were triggered on minimum flows in both the Pee Dee and Waccamaw River systems, water-quality standards were maintained.

The National Pollution Discharge Elimination System permits for the Grand Strand Water and Sewer Authority and other water-reclamation facilities operating in this basin are hydrograph-controlled release permits with loadings consistent with this analysis. The real-time data-collection network for the Grand Strand has been modified to support the operation of these hydrograph-controlled release permits. The network includes streamflow monitors entering the study area on the Pee

Dee River and Waccamaw River and in Little River on the Atlantic Intracoastal Waterway. The streamflow monitoring stations are instrumented with acoustic velocity meters that record tidal streamflow on a 15-minute interval. Wastewater Reclamation Facilities access the real-time streamflow data, either through the internet or automated email, and adjust the effluent discharges to the system according to the streamflow conditions. In addition, water-quality monitors are located in the area of the dissolved-oxygen "sags" to record water temperature, dissolved oxygen, and specific conductance on a 60-minute interval.

References

Carswell, W.J., Sanders, C.L., and Johnson, D.M.: 1988, Freshwater supply potential of the Atlantic Intracoastal Waterway near Myrtle Beach, South Carolina: U.S. Geological Survey Water-Resources Investigations Report 88-4066, 45 p.

Drewes, P.A., and Conrads, P.A.: 1995, Assimilative capacity of the Waccamaw River and the Atlantic Intracoastal Waterway near Myrtle Beach, South Carolina, 1989-92: U.S. Geological Survey Water-Resources Investigations Report 95-4111, 58 p.

Jobson, H.E.: 1997, Enhancements to the Branched Lagrangian Transport Modeling System: U.S. Geological Survey Water-Resources Investigation Report 97-4050, 56 p.

Jobson, H.E., and Schoelhamer, D.H.: 1987, Users manual for a Branched Lagrangian Transport Model: U.S. Geological Survey Water-Resources Investigation Report 87-4163, 73 p.

National Oceanic and Atmospheric Administration: 1995, Tide tables 1995, high and low predictions—East Coast of North and South America, Including Greenland: U.S. Department of Commerce, National Ocean Service, 301 p.

Schaffranek, R.W., Baltzer, R.A. and Goldberg, D.E.: 1981, A model for simulation of flow in singular and interconnected channels: U.S. Geological Survey Techniques of Water-Resource Investigation, book 7, chap. C3, 100 p.

South Carolina Department of Health and Environmental Control: 1991, Agreement on the development of wasteload allocations/total maximum daily loads and NPDES permit limitations, 43 p.

—— 1993, Water classifications and standards (Reg. 61-68) and classified waters (Reg. 61-69) for the State of South Carolina, 36 p.

—— 1999, Total Maximum Daily Load Determination for the Waccamaw River and the Atlantic Intracoastal Water Way Near Myrtle Beach, SC., 80 p.